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JAMMING ON SOME PULSE RADARS

by

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EFFECTS OF RANGE GATE PULL-OFF (RGPO)  
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ABSTRACT

Based on radar ambiguity functions, the effects of range gate pull-off jamming (RGPO jamming) on conventional pulse radars, chirp pulse-compression radars, and binary-coded pulse compression radars are analyzed here. Some useful results are also obtained after comparing the effects.

KEY WORDS: range gate pull-off jamming (RGPO), pulse-compression radar, jamming effect.

1. Introduction

With the advances made in science and technology, modern warfare has advanced from sea, land and air three-dimensional stereo warfare to four-dimensional warfare, including electronic warfare. Local wars taking place in recent years, and particularly the Gulf War, show that electronic warfare has already developed from a pure combat safeguard to a vital operational means. In some ways, the final outcome of a war depends on electronic warfare. Radar is employed as a war telescope, and its performance and whether or not it can work

normally in a complex electromagnetic environment becomes one of the significant factors determining the outcome of a war [1]. To stop enemy radar from operating normally, various jamming measures can be taken [2,3], of which range gate pull-off jamming (RGPO) is an effective jamming mode, which can disable radar range tracking of a target. In this paper the author considers the concept of the ambiguity functions of radar signals, and he analyzes the effect of range gate pull-off jamming on conventional pulse radars, chirp pulse-compression radars, and binary-coded pulse-compression radars.

## 2. Fundamental Theory

### 2.1. Ambiguity Functions [4] and Range Gate Pull-off Jamming [3]

An ambiguity function is defined as

$$\begin{aligned} & \left| \psi(\tau, \xi) \right| \\ &= \left| \int_{-\infty}^{\infty} u(t) u^*(t + \tau) e^{j2\pi\xi t} dt \right| \end{aligned} \quad (1)$$

where  $u(t)$  is the radar transmitted signal;  $*$  is its conjugate.  $|\psi(\tau, \xi)|$  is the difference between two target return waves with a time delay difference  $\tau$  and frequency shift difference  $\xi$ . The smaller the  $|\psi(\tau, \xi)|$ , the larger the difference between two targets can be and therefore, the more easily they can be distinguished. Thus, it is directly associated with "resolving power". In fact, when  $|\psi(\tau, \xi)|$  represents the time  $\tau$ , the matching filter can respond to the radar return wave signal with a Doppler frequency shift  $\xi$ .  $|\psi(\tau, \xi)|$  reaches its maximum value at  $\xi=0$  and  $\tau=0$ . The stereogram plotted on the basis of Eq. (1) is referred to as an ambiguity plot. In practice, usually a plane is made parallel to the  $\tau$ - $\xi$  plane at 6dB below the maximum value. The cross trace between this plane and the ambiguity plot is projected onto the  $\tau$ - $\xi$  plane to form a projection plot called the ambiguity degree plot. Generally speaking, a target located in the ambiguity degree plot cannot be resolved.

RGPO signifies that the jammer, upon receiving a radar signal, duplicates, after a certain regular time delay, a false signal larger than the radar return wave and transfers it to the radar so as to destroy normal range tracking of the target.

## 2.2. RGPO Jamming of Conventional Pulse Radar

Suppose the normalized envelope of a conventional pulse radar is

$$u(t) = \begin{cases} 1/\sqrt{T} & 0 < t < T \\ 0 & \text{Others} \end{cases} \quad (2)$$

where  $T$  is pulse width.

Then its ambiguity function is

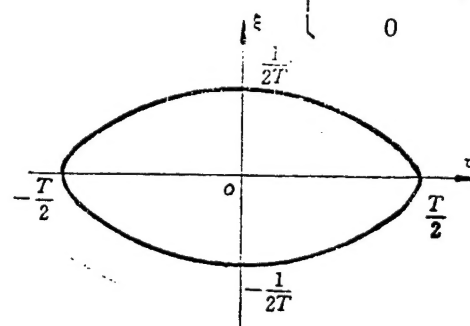
$$|\psi(\tau, \xi)| = \begin{cases} \frac{\sin[\pi\xi(T-|\tau|)]}{\pi\xi[T-|\tau|]} \cdot \frac{T-|\tau|}{T} & |\tau| < T \\ 0 & |\tau| \geq T \end{cases} \quad (3)$$


Fig. 1. Ambiguity degree plot of a conventional pulse radar signal

This ambiguity degree plot is shown in Fig. 1. This signal has a time width  $\tau=T$ , bandwidth  $B=1/T$ , and compression ratio  $CR=1$ . If the target return wave and range gate pull-off jamming are within the ambiguity degree plot, then the radar cannot resolve the two signals, i.e., the time delay difference between the two signals is at least  $T/2$ . At this instant, range gate pull-off jamming is effective, for the radar range tracking wave gate locks on the

jamming instead of the target.

### 2.3 RGPO Jamming of Chirp Pulse-Compression Radar

The normalized envelope of a chirp pulse-compression radar is

$$u(t) = \begin{cases} \frac{1}{\sqrt{T}} e^{j\frac{\mu t^2}{2}} & 0 < t < T \\ 0 & \text{Others} \end{cases} \quad (4)$$

where  $\mu$  is the frequency modulation coefficient.

The frequency modulation width of the signal, i.e., its effective bandwidth  $B = \mu T / 2\pi$ , the effective pulse width is usually  $\tau = 1/B = 2\pi / \mu T$ , the compression ratio  $CR = \mu T^2 / 2\pi$  and generally  $CR > 1$ . Its ambiguity function is

$$\begin{aligned} & |\psi(\tau, \xi)| \\ &= \frac{T - |\tau|}{T} \cdot \frac{\sin\left[\left(\pi\xi - \frac{\mu\tau}{2}\right)(T - |\tau|)\right]}{\left(\pi\xi - \frac{\mu\tau}{2}\right)(T - |\tau|)} \end{aligned} \quad (5)$$

Its ambiguity degree plot is shown in Fig. 2. It is virtually an ambiguity degree plot of a conventional pulse signal turning at an angle. This angle is related to the frequency modulation coefficient  $\mu$ , and the maximum value of the ambiguity degree plot is located on line MN. The point of intersection between the ambiguity degree plot and the  $\tau$  axis is  $\pm 1/2B$ , located somewhere between  $\pm 0.5T$ . Thus, with the same pulse width, a smaller pull-off scope is enough to successfully cause this radar to follow the jamming, compared with a conventional pulse radar.

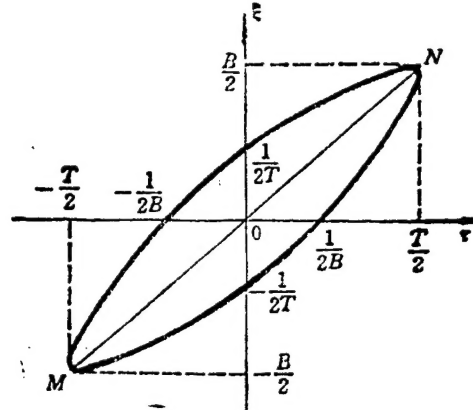


Fig. 2. Ambiguity degree plot of a chirp pulse-compression radar signal

There are two methods of imposing range gate pull-off jamming on a chirp pulse-compression radar. One of them serves to duplicate, after an appropriate time delay, the received radar signal, forming a signal larger than the radar return wave and then transferring it to the radar. The other method is to accomplish range gate pull-off jamming through frequency cheating jamming [5]. The theoretical basis of the latter method is that the coupling action between the time delay  $\tau$  and frequency shift  $\xi$  of the chirp signal can be calculated through two-dimensional integrating estimation, i.e., with a frequency shift  $\Delta\xi$ , there must be a corresponding time variable  $\Delta\tau$ . In other words, range pull-off can be realized through frequency pull-off.

#### 2.4. RGPO Jamming on Binary-coded Pulse-Compression Radar

The normalized envelope of binary-coded pulse-compression radar can be expressed as

$$\begin{aligned}
 u(t) &= \frac{1}{\sqrt{pt_d}} e^{j\phi(t)} \\
 &= u_1(t) \otimes u_2(t)
 \end{aligned} \tag{6}$$

where  $t_d$  is subpulse width;

$P$  is number of subpulses;

$$\phi(t) = \{0, \pi\};$$

$u_1(t)$  and  $u_2(t)$ , respectively, can be expressed as

$$u_1(t) = \begin{cases} \frac{1}{\sqrt{t_p}}, & 0 < t \leq t_p \\ 0, & \text{Others} \end{cases} \quad (7)$$

$$u_2(t) = \frac{1}{\sqrt{p}} \sum_{k=0}^{p-1} C_k \delta(t - kt_p) \quad (8)$$

Here  $C_k = e^{j\phi_k} = \{+1, -1\}$

then the ambiguity function of  $u(t)$  is

$$|\psi(\tau, \xi)| = \left| \sum_{n=p+1}^{p-1} x_1(\tau - nt_p) \cdot \xi \cdot x_2(mt_p \cdot \xi) \right| \quad (9)$$

where  $x_1(\cdot)$  and  $x_2(\cdot)$ , respectively, are the ambiguity functions of  $u_1(\cdot)$  and  $u_2(\cdot)$ .

$$\begin{aligned} x_1(\tau, \xi) &= \\ &= \begin{cases} e^{j\pi\xi(t_p - \tau)} \left[ \frac{\sin \pi\xi(t_p - |\tau|)}{\pi\xi(t_p - |\tau|)} \right] \\ \cdot \left( 1 - \frac{|\tau|}{t_p} \right) & |\tau| < t_p \\ 0 & \text{Others} \end{cases} \end{aligned} \quad (10)$$

$$\begin{aligned} x_2(\tau, \xi) &= \\ &= \begin{cases} \frac{1}{p} \sum_{k=0}^{p-1-m} C_k C_{k+m} \\ \cdot e^{j2\pi\xi k t_p} & (0 \leq m \leq p-1) \\ \frac{1}{p} \sum_{k=-m}^{p-1} C_k C_{k+m} \\ \cdot e^{j2\pi\xi k t_p} & -(p-1) \leq m < 0 \end{cases} \end{aligned} \quad (11)$$

When  $p$  subpulses with width  $t_p$  are coded, the matching filter will generate an effective peak value that is  $p$  times higher than the amplitude of the input pulse, and its ambiguity degree plot is shown in Fig. 3. The signal pulse width  $T = pt_p$ ; effective bandwidth  $B = 1/t_p$ ; effective time width  $\tau = 1/B = t_p$ ;

compression ratio  $CR=0$ .

It is known from the figure that the response bandwidth of the matching filter is  $1/T$ . When there is a Doppler frequency mistuning between the return wave signal and matching filter, the filter can hardly provide frequency cheating jamming for this radar because it cannot execute satisfactory compression. On the contrary, the binary-coded pulse-compression radar signal enjoys a higher range resolving power compared with the conventional pulse radar signal. Only if a small time delay is imparted to the transmitted signal before the signal is transferred to the radar, can it produce effective range cheating for the radar. Subsequently, range gate pull-off jamming can be effective for this kind of signal.

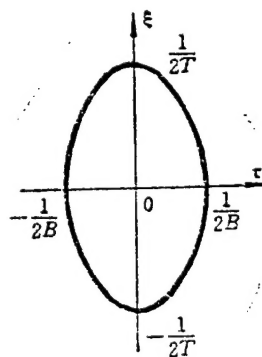


Fig. 3. Ambiguity degree plot of a binary-coded pulse-compression radar signal

At present, due to the limitations of the microwave signal memory technology, it is difficult to impose RGPO for complex in-pulse modulation signals, including binary-coded signals. However, with the development and application of the coherent microwave signal memory devices and particularly, digital radio frequency memory (DRFM) technology, the application of RGPO to complicated in-pulse modulation signals will be accomplished.

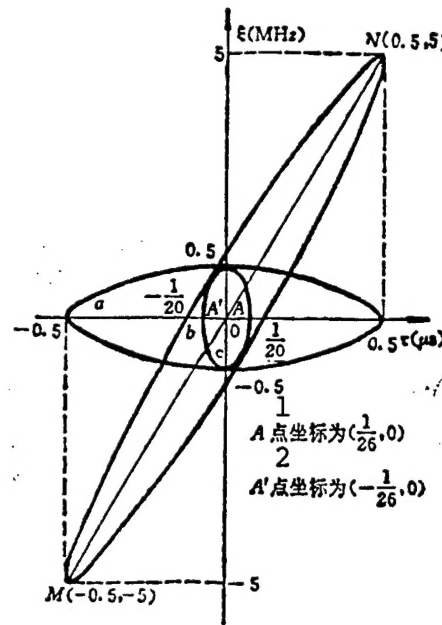


Fig. 4. A comparison among ambiguity degree plots  
 KEY: (1) A point coordinate is  
 (2) A' point coordinate is

### 3. Conclusions

Based on the ambiguity functions of radar signals, the effect of range gate pull-off jamming on three kinds of pulse radar signals was analyzed. It can be concluded that the range resolving power of chirp pulse-compression radar signals and binary-coded pulse-compression radar signals are far higher than that those of conventional pulse radars. Similarly, range gate pull-off jamming has a far better effect on the former two than on the latter. For chirp pulse-compression radar signals, range gate pull-off jamming can be realized through direct time delay or frequency shift. For complex pulse radar signals, such as binary-coded pulse-compression radar signals, range gate pull-off jamming still presents some difficulties at present, due to the limitations of microwave signal memory technology. Fig. 4 shows the ambiguity degree plots of the three kinds of radar signals

with the same pulse width, where a is the ambiguity degree plot of a conventional pulse radar signal with  $1\mu\text{s}$  pulse width; b is the ambiguity degree plot of a chirp pulse-compression radar signal with a  $1\mu\text{s}$  pulse width within a 10-MHz frequency modulation scope; c is the ambiguity degree plot of a 13-bit Barker code pulse signal with a  $1\mu\text{s}$  pulse width. At  $\tau=0$ , the three plots possess an identical frequency resolving power, while their compression ratio, respectively is 1, 10 and 13; b and c are far superior to an in-range resolving power. It is obvious that range gate pull-off jamming has a better effect on b and c than on a.

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